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Stabilization Studies on Soil-Cement Mixtures for Experimental Lining-Logan Experimental section--Logan, Utah

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

STABILIZATION STUDIES ON SOIL-CEMENT
MIXTURES FOR EXPERIMENTAL LINING
LOGAN EXPERIMENTAL SECTION--LOGAN, UTAH

Earth Materials Laboratory Report No. EM-170

RESEARCH AND GEOLOGY DIVISION



BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

APRIL 19, 1948

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Research and Geology Division
Geology Section
Earth Materials Laboratory
Denver, Colorado
April 19, 1948

Laboratory Report No. EM-170
Tests by: R. S. McMechen
Checked by: W. A. Clevenger
R. S. McMechen
Written by: V. S. Meissner
Reviewed by: W. G. Holtz

Subject: Stabilization studies on soil-cement mixtures for
experimental lining--Logan Experimental Section--Logan, Utah.

INTRODUCTION

A Memorandum of Agreement has been written between the Soil Conservation Service and the Bureau of Reclamation, relative to the experimental installation of test sections of soil-cement and asphaltic canal linings to determine their durability and permeability. These test sections are to be installed at the Experimental Station, Logan, Utah. The Bureau of Reclamation requested two types of soil for the soil-cement studies, a fine sandy soil, poorly graded with little or no silt (Classification Symbol SP) and a fine sandy soil with excess silt (Classification Symbol SF-Silty). The gradation limits for these two soil types are shown on Figures 1 and 2. Three soil samples were transmitted by letter of November 13, 1947, from Dr. C. W. Lauritzen. Gradation tests on these soils revealed that two of the samples were too fine to provide suitable soil-cement lining but that the Trenton fine sandy loam would satisfy the "SF-Silty" requirement. The soil-cement tests have been completed on this material and additional soil of the "SP" type has been requested. The results of the asphaltic lining investigation have been reported by letter from R. F. Blanks to the Soil Conservation Service, dated January 16, 1948.

SUMMARY

The laboratory tests indicate that the Trenton fine sandy loam, Laboratory Soil No. 11H-24, can be mixed with portland cement to produce a canal lining of satisfactory hardness, durability, and permeability. A standard soil-cement mixture containing a minimum of 12 percent cement by volume (3.24 sacks of cement per cubic yard) compacted to maximum density at optimum moisture content should produce a suitable canal lining.

DISCUSSION OF LABORATORY TESTS

The mechanical analysis tests made on the three samples indicated that two materials (11H-23 and 11H-25) contained too much silt and clay to provide a satisfactory soil-cement mixture (see Figure 3). No soil-cement tests were performed on these samples.

Sample 11H-24 is classified "SF-silty" by the Modified Casagrande Classification, and is satisfactory for testing. The moisture limits tests (liquid limit = 18 and plasticity index = 0) and the mechanical analysis place this material in Group A-2 according to the Public Roads Administration classification. Previous tests on soil-cement mixtures show that a soil of this type can be stabilized by 6 to 12 percent cement by volume. With this information, tests were undertaken to determine the amount of cement necessary to stabilize the soil. A list of the tests conducted is included in the Appendix.

Standard laboratory tests were made on the natural soil and on soil-cement mixtures containing approximately 6 and 14 percent cement by volume. The compaction curves are shown on Figure 4 in the Appendix, and the following tables show the variation in maximum density and optimum moisture due to the change in cement content.

COMPACTION DATA
(11H-24)

Cement content:		Cement content:		Maximum dry:	Optimum
by volume	:	by weight	:	density	moisture content
(percent)	:	(percent)	:	(pcf)	(percent)
0	:	0	:	108.3	12.6
6.24	:	5.49	:	112.7	12.2
15.02	:	13.83	:	116.2	11.4

The compaction curves, Figure 4, show that the maximum density increases and the optimum moisture content decreases with increasing cement content.

The quantities of soil, cement, and water required to produce specimens containing 6, 8, 10, 12, and 14 percent cement by volume when compacted to maximum density at optimum moisture were calculated by interpolation from the compaction data. Two types of specimens are required for the stability tests. One, called the volume and moisture change specimen, is used to determine the volume and moisture changes which occur during either the wet-dry or freeze-thaw test. The other specimen, called the soil-cement loss specimen, is vigorously brushed after each cycle of either the wet-dry or the freeze-thaw test to remove the loosened material from the specimen. Four soil-cement loss specimens, containing 8, 10, 12, and 14 percent cement by volume, and one volume and moisture change specimen, containing 12 percent cement by volume, were molded for use in the wetting and drying test. A similar

set of specimens were molded for use in the freezing and thawing test. The data from the tests provide information for determining the volume changes, the moisture changes, and the soil-cement losses. The information compiled during the tests on these soil-cement mixtures is contained in the following table:

STABILITY TEST DATA
Standard Soil-cement Mixtures

Cement content by volume (percent)	Cement content by weight of soil (percent)	Dry density (pcf)	Moisture content (percent)	Maximum moisture content (percent)	Satura- tion moisture (percent)	Maximum volume change (percent)	Total soil cement loss (percent)
			Wetting and Drying Test				
7.90	7.10	112.0	12.2				29.0
9.90	8.97	113.1	11.9				10.1
11.84	10.88	113.4	11.9	13.5	17.7	-0.5	4.0
13.79	12.82	114.1	11.5				2.4
			Freezing and Thawing Test				
7.88	7.10	111.8	12.2				30.8
9.87	8.97	112.8	12.0				11.4
11.87	10.88	113.8	11.8	14.3	17.9	-0.3	6.9
13.80	12.82	114.2	11.7				3.9

Figure 5, Appendix, illustrates graphically the relation between cement content by volume and the soil-cement losses after 12 cycles of both the wet-dry and the freeze-thaw tests for the standard soil-cement mixture. Photograph 1 shows the soil-cement specimens after 12 cycles of wetting and drying and Photograph 2 shows the specimens after 12 cycles of freezing and thawing.

Compression test specimens, 2 inches in diameter and 2 inches high, containing 6, 10, and 14 percent cement by volume, were molded at optimum moisture and maximum density for testing after 2, 7, and 28 days of curing. The specimens were immersed in water for 1 hour before breaking. The table below shows the compressive strengths (average of three specimens) of the soil cement mixtures in pounds per square inch.

COMPRESSIVE STRENGTH (Average of Three Specimens)				
Cement content by volume (percent)	Compressive strength (pounds per square inch)			
	2 days	7 days	28 days	
6	115	175	285	
10	275	420	680	
14	535	760	1,140	

The following criteria have been established by the Portland Cement Association for the selection of cement contents necessary to produce soil cement in the laboratory of satisfactory hardness, durability, and serviceability:

- a. Soil-cement losses during 12 cycles of either the wet-dry or the freeze-thaw test shall not exceed 14 percent for a soil of the Public Roads Administration, Soil Group A-2.
- b. The maximum volume at any time during either the wet-dry test and the freeze-thaw test shall not exceed the volume at the time of molding by more than 2 percent.
- c. The maximum moisture content during either the wet-dry test or the freeze-thaw test shall not exceed that quantity which will completely fill the voids of the specimen at the time of molding.
- d. The compressive strength of 2-inch soil-cement test specimens shall increase with age and cement content.
- e. For soils containing less than 35 percent silt and clay, the cement content recommended for field installations shall be 2 percent higher than the amount necessary to produce satisfactory soil cement in the laboratory.

The freezing and thawing test provided the most severe condition for the soil-cement mixtures. Figure 5 in the Appendix shows that 10 percent cement by volume would satisfy criterion (a). The volume and moisture change criteria (b) and (c) are satisfied by the soil-cement mixtures as is the compressive strength criterion (d).

A permeability test on a soil-cement specimen containing 6 percent cement by volume was made. An 8-inch diameter by 3-inch deep specimen was used and the test was conducted in accordance with standard procedure except that a plexiglass cylinder instead of the standard metal container was used, permitting the test to be made without loading the sample. The soil-cement mixture was placed at maximum density and optimum moisture and was found to have a percolation rate of 0.53 foot per year.

RECOMMENDATIONS

In compliance with criterion (e) it is recommended that for field installation of the soil cement, a minimum of 12 percent cement by volume be incorporated in the mixture. The following table includes the recommended cement content and other pertinent information for the soil-cement mixture.

STANDARD SOIL-CEMENT MIXTURE (Sample 11H-24)

Maximum dry density, soil plus cement--pcf	115.0
Moisture content, by dry weight of soil plus cement--percent	11.6
Cement content, by volume--percent	12.0
Cement content, by weight of dry soil-- percent	10.88
Cement, soil, water proportions by weight	1:9.2:1.18
Cement, pounds per square yard, 3-inch thickness	25.38
Cement, sacks, per cubic yard in place	3.24
Water, gallons per cubic yard in soil-cement mixture	43.2

Appropriate specifications for soil-cement linings, included in the Appendix, involve the foundation preparation, conditioning of the soil, mixing and placing the soil-cement mixture, and curing the completed lining.

APPENDIX

TEST PROCEDURES

Standard properties test. The standard properties tests are performed in accordance with the procedure outlined in the Bureau of Reclamation Publication, Laboratory Procedure in Testing Earth Material for Foundation and Construction Purposes, dated July 21, 1946. The detailed procedures are given in the following pages of the publication.

a. Mechanical Analysis	40
b. Specific Gravity	57
c. Compaction Test	68
d. Percolation Test	75

Stability tests. The stability and other pertinent test are performed in accordance with the following ASTM procedures:

- a. Standard Method of Test for Liquid Limit of Soils--ASTM Designation: D 423-39
- b. Standard Method of Test for Plastic Limit and Plasticity Index of Soils--ASTM Designation: D 424-39
- c. Standard Method of Wetting and Drying Test of Compacted Soil-cement Mixtures--ASTM Designation: D 559-44
- d. Standard Method of Freezing and Thawing Test of Compacted Soil-cement Mixtures--ASTM Designation: D 560-44

SPECIFICATIONS

General

Description

This item shall consist of a canal lining composed of a combination of soil and portland cement uniformly mixed, moistened, and compacted in accordance with this specification, and shaped to conform to the lines, grades, thicknesses, and typical cross-section shown on the plans. Construction shall proceed as follows:

a. Soil quantities for the canal to be paved shall be carefully balanced to provide the quantity of satisfactory soil required to produce final line and grade.

b. The soil in the canal to be paved shall be thoroughly pulverized on the berm, slopes, or bottom.

c. Portland cement shall be uniformly added and mixed with the pulverized soil.

d. Water shall be added as needed with a distributor and shall be uniformly incorporated into the soil-cement mixture in the amounts required to attain the optimum moisture content for the soil-cement mixtures at the time of compaction.

e. The moistened soil-cement mixture shall be spread over the slopes or bottom to give a uniform compacted thickness conforming to the required depth, grade, and line.

f. The mixture shall be compacted uniformly with sheepsfoot, flat, or other rollers as specified, in one continuous operation from the bottom to the top surface. The mixture shall be compacted at the optimum moisture content and to the density specified.

g. After compaction is completed, the surface shall be shaped, and then finished with a smooth-wheeled roller supplemented by spike-tooth harrows, nail drags, broom drags, and by pneumatic tire rolling.

Materials

Portland Cement

Standard brand to conform to requirement and tests of the "Standard Specification for Portland Cement," ASTM Designation: C 150-46, Type I. One (1) cubic foot of portland cement shall be considered as weighing 94 pounds.

Water

The water used in the construction of the canal to be lined shall be free from salt, oil, acid, organic matter, or other deleterious substances.

Soil

The soil for the canal lining shall consist of the natural material in the area, or selected soil as specified.

Construction Methods

Trimming Foundation for Soil-cement Lining

The bottom and side slopes shall be finished accurately to the dimensions shown on the drawings. Where the foundation materials are loose, the foundation surfaces shall be moistened with water and tamped with suitable tools for the purpose of thoroughly compacting them and forming firm foundation on which to place soil-cement lining.

Pulverizing

A sufficient quantity of the soil to be treated shall be pulverized by pugmill or road mixing methods or comparable mixing methods to give the compacted cross-section shown on the plans, either on the berm or bottom of the canal. The pulverizing shall be done prior to the application of the cement. Pulverizing shall continue until 80 percent of the soil, by dry weight, exclusive of gravel or stone, shall pass a No. 4 sieve.

Prior to the application of cement, the soil shall be manipulated until the percentage of moisture in the soil does not exceed by more than 2 percentage points the optimum moisture content specified for the soil-cement mixture before compaction.

Cement shall only be applied to such a quantity of soil that mixing, moistening, and compaction (except for final shaping) can be continuous and completed within 1 hour after the beginning of water application to the thoroughly mixed soil-cement.

Mixing

Immediately after the cement has been distributed, it shall be mixed with the loose soil. The mixing may be accomplished with cultivators, gang plows, disc harrows, rotary speed mixers, or other approved implements. The mixing shall be continued for as long as necessary to

insure a thorough, uniform, and intimate mix of the soil and cement and until the resulting mixture is homogeneous and uniform in appearance. When traveling or stationary pugmill mixers are available, the pulverizing, moistening, and cement application can be performed in one continuous operation.

Application of Water

Immediately after the mixing of soil and cement is complete, the moisture content of the soil cement shall be determined, and if required, water shall be uniformly applied in such quantities and at such a rate that all wetting and mixing required on the section shall be completed in 1 hour. Each increment of water shall be partially incorporated with the soil to prevent concentration of the water near the surface. After the last increment of water has been added, mixing shall be continued with the implements used for mixing the soil and cement until the moisture is uniformly distributed throughout the mixture. When water spreading and mixing is completed, the percentage of moisture in the mixture, on the basis of dry weight, shall not vary from the specified optimum moisture content of the soil-cement mixture by more than one-tenth for mixtures consisting of soils of the A-1, A-2, or A-3, PRA soil groups having less than 30 percent aggregate retained on the No. 4 sieve. With soils of A-4 or higher classification and with soils containing 30 percent or more of plus No. 4 aggregate, the percentage of moisture in the soil-cement mixture shall not be below the specified optimum moisture nor more than one-fifth above the specified optimum moisture. This specified optimum moisture shall be that prevailing in the moist soil cement at the time of compaction, and shall be determined in the field by a moisture-density test on representative samples of soil-cement mixture, unless this has already been done in the laboratory.

When any of the operations after the initial application of water to the soil-cement mixture is interrupted for more than 30 minutes for any reason, or when the uncompacted soil-cement mixture is wetted by rain so that the average moisture content exceeds the tolerance outlined above at the time of final compaction, the active section shall be reconstructed in accordance with this specification. All material along longitudinal or transverse construction joints not properly compacted shall be removed and replaced with properly moistened and mixed soil cement which shall be compacted to specified density.

Compaction

Prior to compaction the mixture shall be spread on the slopes or bottom of the canal to a depth sufficient to give the compacted depth shown on the plans. Usually 7 to 9 inches of material are required to give a finished depth of 6 inches. Materials that are mixed in place shall be loosened for the full depth. The mixture shall then be uniformly compacted by sheepfoot rolling until the entire depth and width

of soil-cement mixture is uniformly compacted to the specified density except that the sheepsfoot roller shall be removed when about 1 inch of loose mulch remains. The sheepsfoot roller shall be of the size, shape, and weight best suited to give the required densities in the soil-cement mixture being compacted. A granular soil containing little or no minus No. 200 sieve material which does not compact to required densities with sheepsfoot rollers may be compacted with smooth or pneumatic tire rollers. The rate of operation and numbers of rollers shall be sufficient to compact uniformly the section of canal being processed for the specified depth within 2 hours. Smooth or pneumatic rollers should be used entirely when the lining thickness is less than 5 inches.

After the mixture, excepting the top 1 inch of mulch, is compacted, the surface of the canal being processed shall be reshaped to the required lines, grades, and cross-section and then shall be lightly scarified to loosen any imprint left by the compacting or shaping equipment, until a surface mulch of about 1 inch in thickness is obtained. The resulting surface then shall be thoroughly rolled with a smooth wheel tandem roller or pneumatic tire rollers. The rolling shall be supplemented with the use of nail drags and broom drags. These surface finishing methods may be varied from this procedure, provided a dense, uniform surface, free of surface compaction planes is produced. The moisture content of the surface material must be maintained at its specified optimum during all finishing operations. Surface compaction and finishing shall be done in such a manner as to produce, in not over 2 hours, a smooth, closely knit surface, free of cracks, ridges, or loose material, conforming to the sections shown on the plans.

Initial compaction, surface compaction, and finishing may be accomplished by longitudinal rolling in the bottom of the canal. However, this may be impractical on the canal slopes and transverse rolling may be necessary. Longitudinal or transverse rolling in the bottom or on the slopes shall be permitted if the finished lining conforms to this specification.

Protection and Cover

After the canal lining has been finished as specified herein, it shall be protected against rapid drying for a period of 7 days by applying a 2-inch covering of earth which shall be moistened initially and subsequently as may be necessary, or other moisture retaining materials such as hay, straw, or burlap may be used.

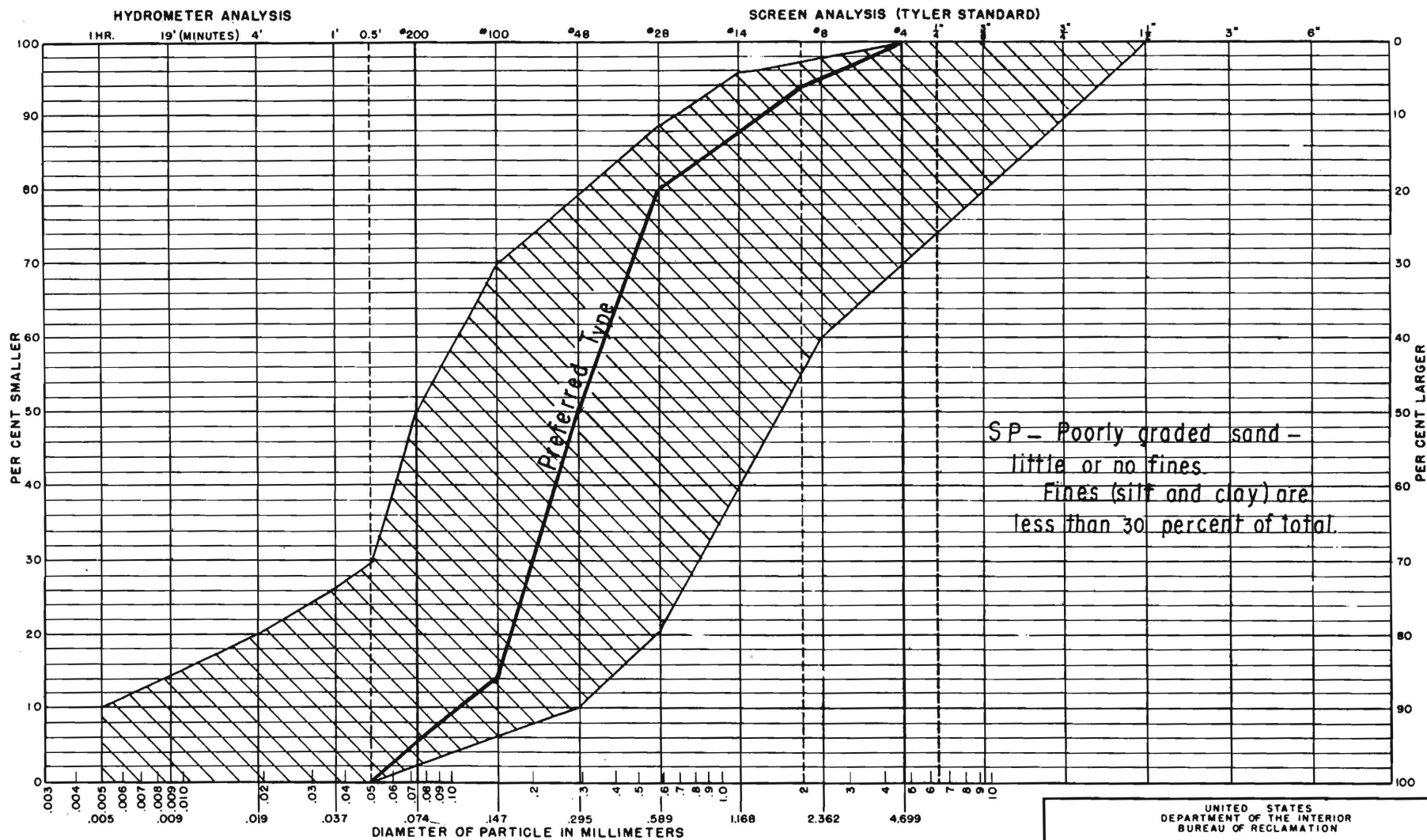
Any finished portion of the canal adjacent to construction which is traveled by equipment used in constructing on adjoining section shall be continuously covered with at least 6 inches of earth to prevent equipment from marring the surface of the completed work.

Alternate Methods of Construction

This specification calls for construction equipment and methods similar to road and street paving specification. However, a machine or combination of machines which will meet these specifications for pulverizing the soil, spreading cement or water, mixing the materials, or compacting and finishing the mixture to specified depth, lines, and grade may be used in lieu of the method specified herein.

Alternate equipment may include traveling or stationary pugmill or concrete mixers, Roto-tillers or other types, or pulverizing, mixing, spreading, and compaction machinery. When machine mixing is used, the resulting soil-cement mixture shall be compacted to the optimum moisture content specified before there is any appreciable moisture loss and the compaction operation shall be a continuation of the mixing operation in such a manner that the moistened soil-cement mixture does not remain undisturbed, after mixing and before compacting, for more than 30 minutes.

Pneumatic tampers may be used in lieu of rolling equipment specified herein, provided comparable compaction and finishing results are obtained.



NOTES:

REV. 4-3-1946

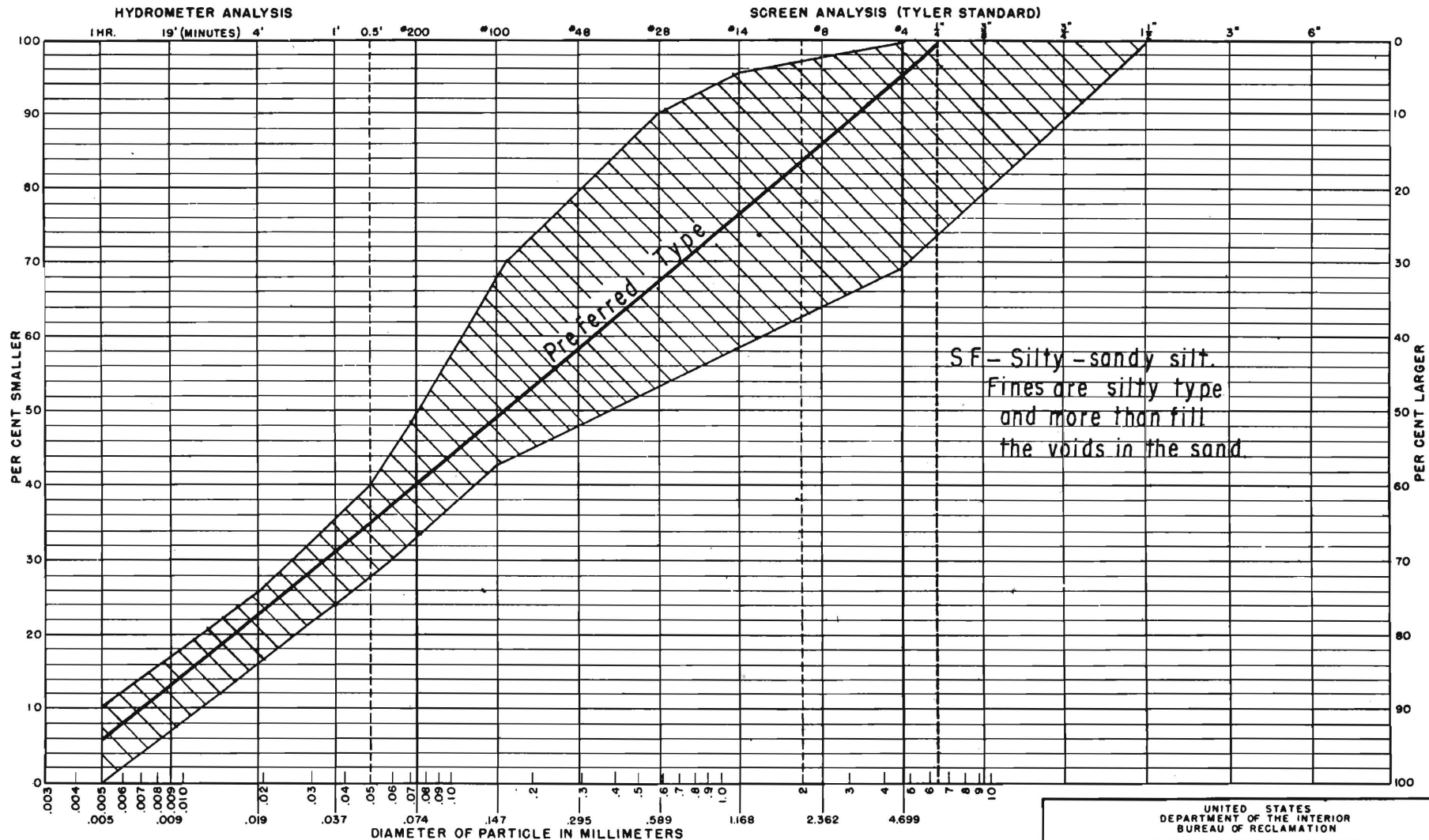
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GRADATION TEST

**APPROXIMATE LIMITS
FOR SP
POORLY GRADED SAND**

DRAWN V.S.M. CHECKED W.A.C. DATE 11-10-47

FIGURE 1



CLAY	SILT	VERY FINE SAND	FINE SAND	MEDIUM SAND	COARSE SAND	VERY COARSE SAND	GRAVEL	MODIFIED BUREAU OF SOILS CLASSIFICATION
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NOTES:

REV. 4-3-1946

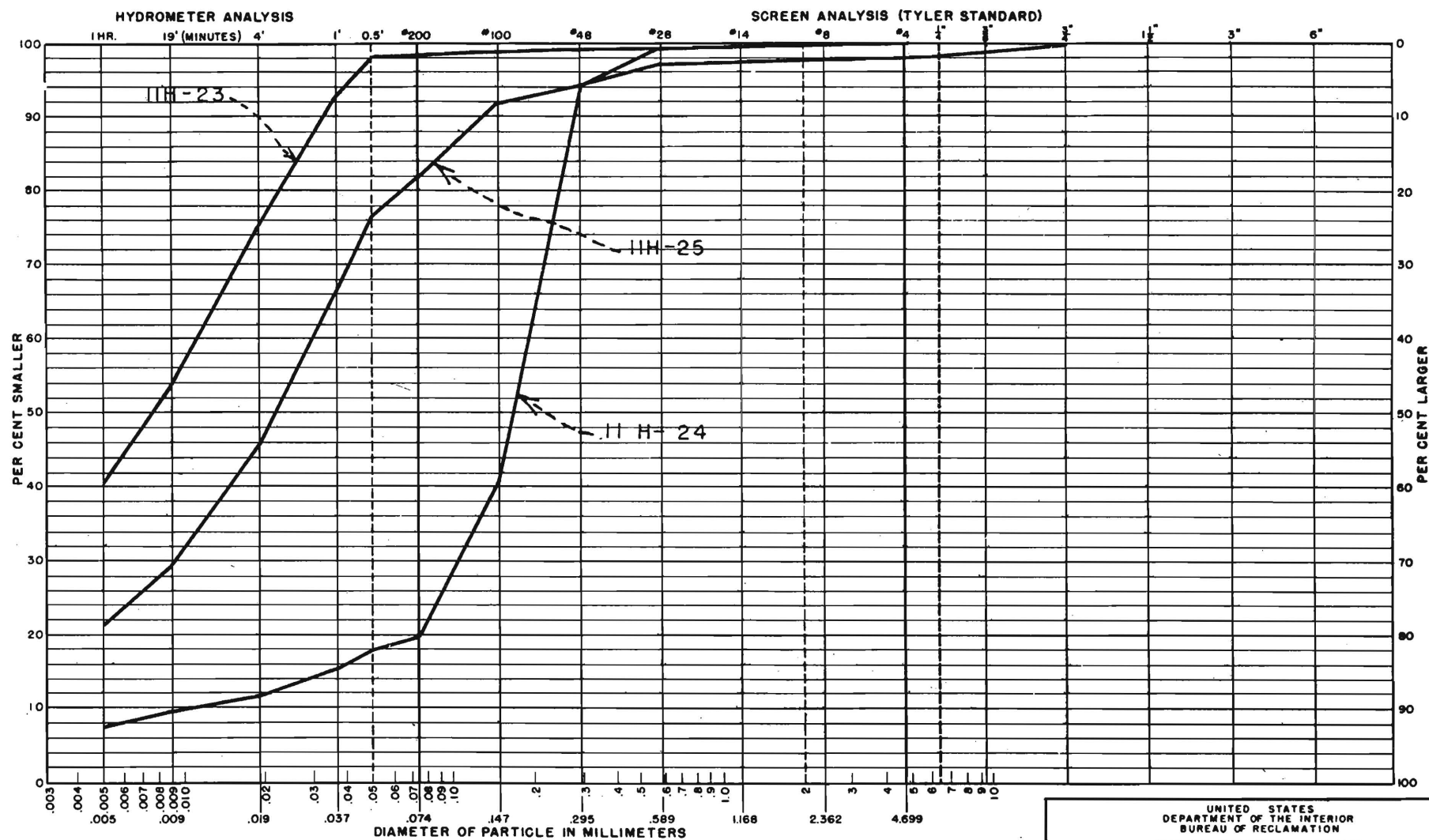
UNITED STATES
DEPARTMENT OF THE INTERIOR
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GRADATION TEST

APPROXIMATE LIMITS
FOR SF SILTY
SANDY SILT

DRAWN V.S.M. CHECKED W.A.C. DATE 11-10-47

X-D-2424



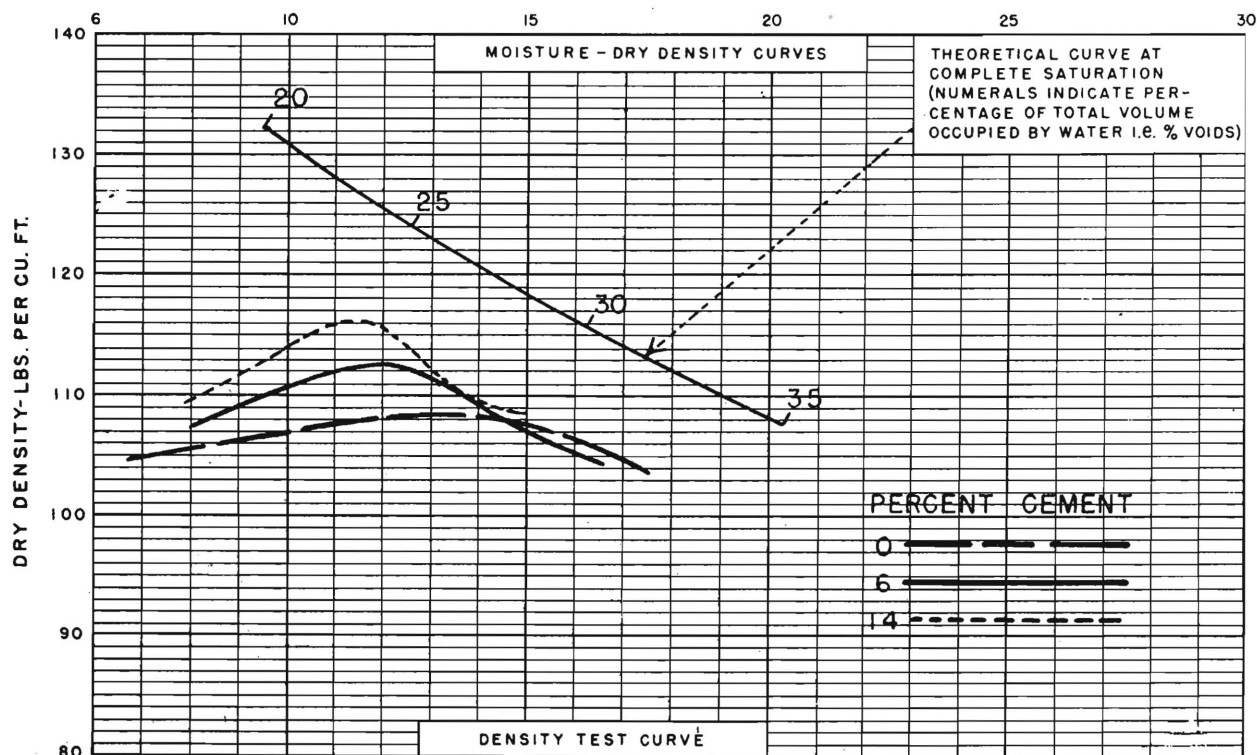
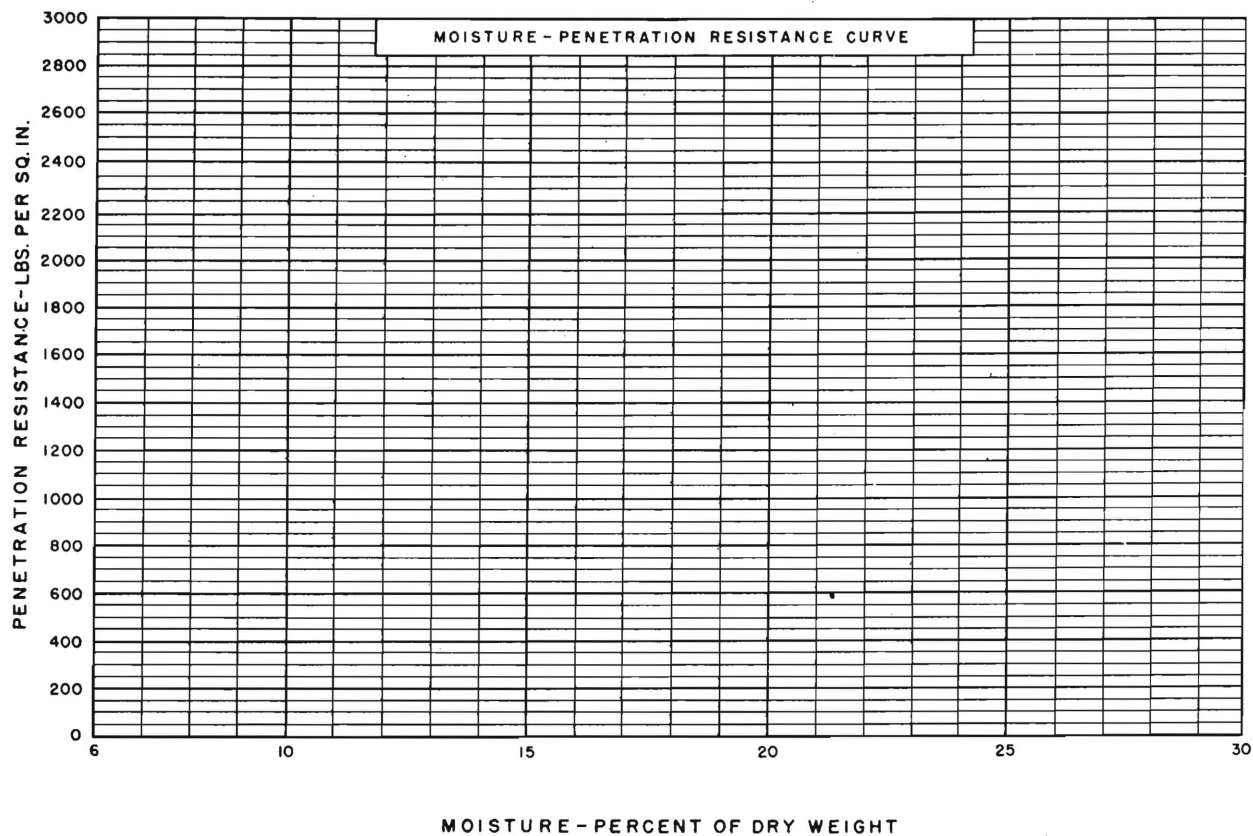
NOTES: IIIH-23, SALT LAKE, Silt Loam
 IIIH-24, TRENTON, Fine Sandy Loam.
 IIIH-25, MILLVILLE, Silt Loam

UNITED STATES
 DEPARTMENT OF THE INTERIOR
 BUREAU OF RECLAMATION

GRADATION TEST
 LOGAN UTAH
 EXPERIMENTAL
 SOIL-CEMENT CANAL LINING

DRAWN R. M. CHECKED V.S.M. DATE 1-15-48

X-D-2424



25 COMPACTION
BLOWS PER LAYER

3 LAYERS

5.5 LB. HAMMER

18 IN. DROP

2.65 SOIL PROPERTIES
SPECIFIC GRAVITY

SF-silty SOIL CLASSIFICATION

0 % LARGER THEN TESTED

108.3 MAX. DRY DENSITY (P.C.F.)

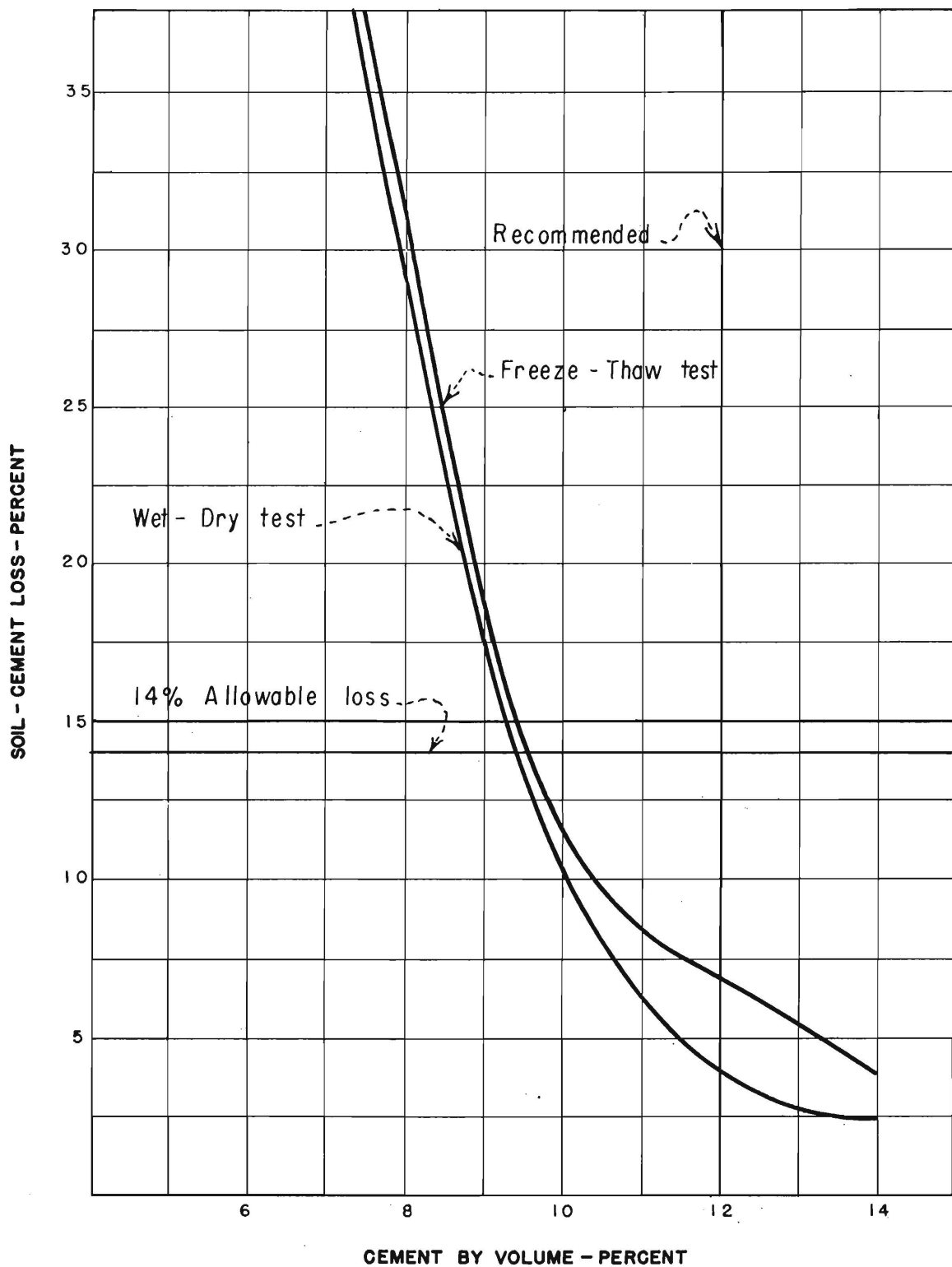
12.6 OPT. MOISTURE (%)

— PEN RES. AT OPT. MOIST. (PSI)

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COMPACTION TEST CURVES
LOGAN UTAH
EXPERIMENTAL
SOIL-CEMENT CANAL LINING

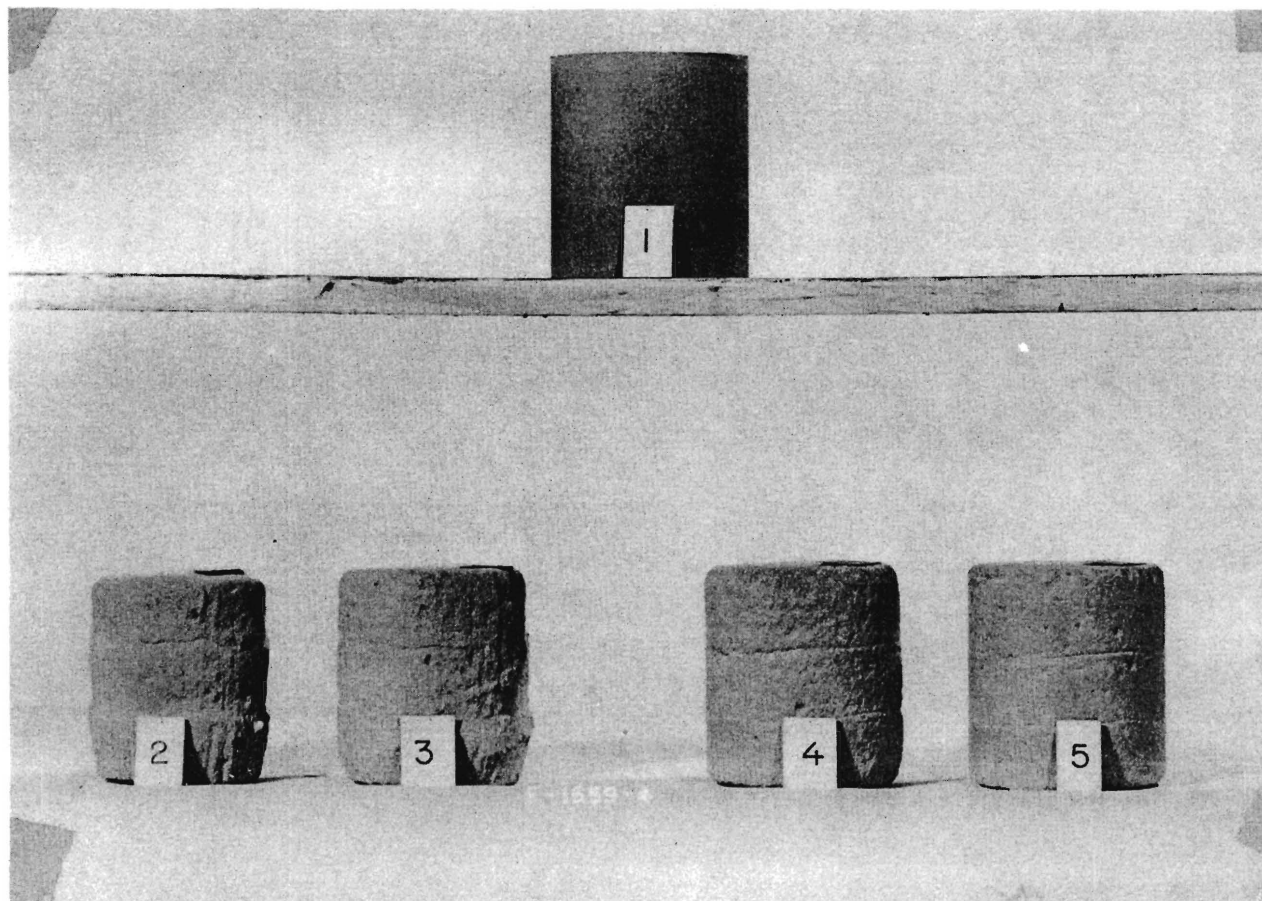
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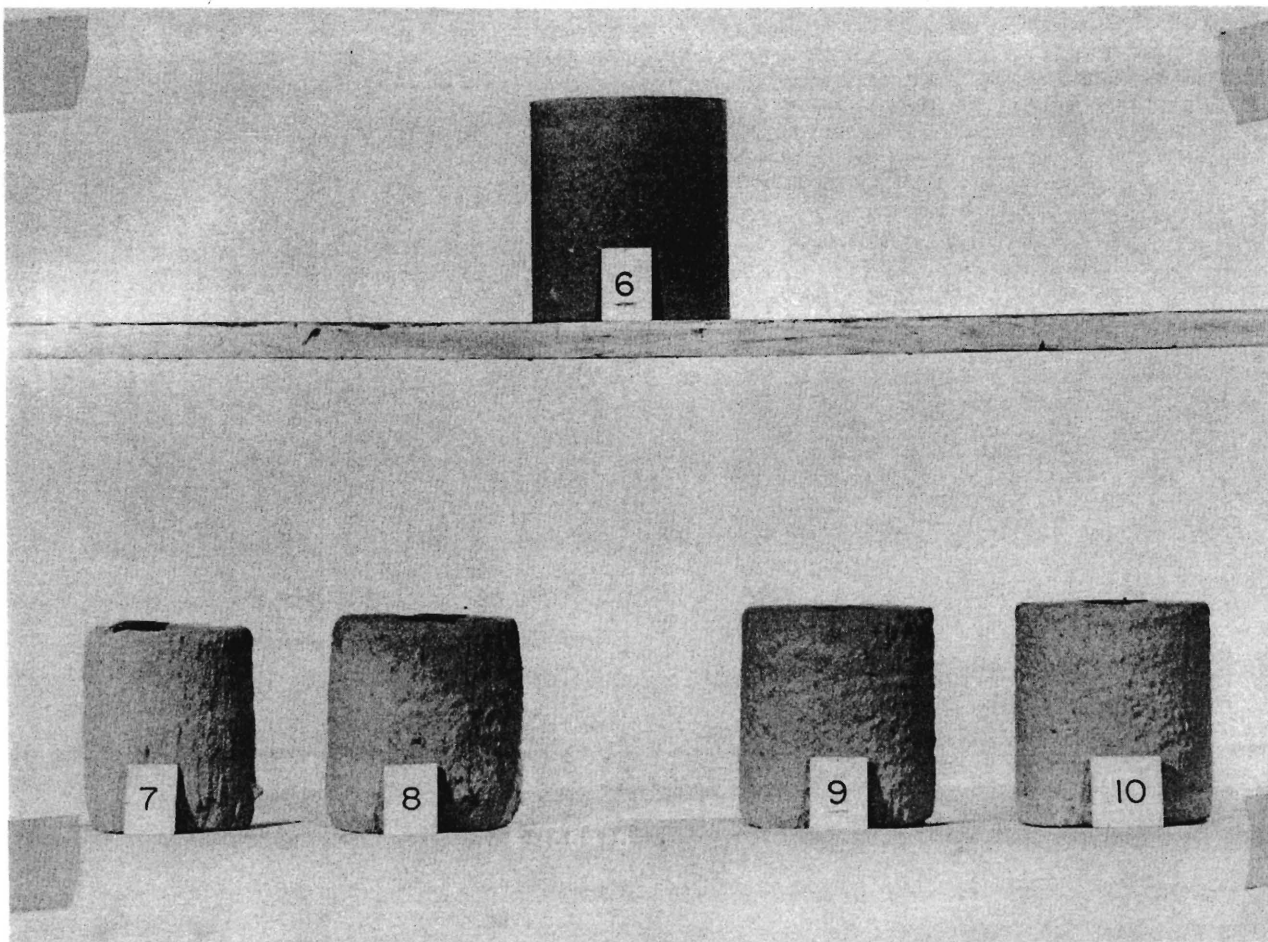
I H - 24 STANDARD
SOIL-CEMENT SPECIMENS

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SOIL-CEMENT LOSSES
LOGAN UTAH
EXPERIMENTAL
SOIL-CEMENT CANAL LINING

DRAWN R. S. M. CHECKED V. S. M. DATE 4-6-48



Standard Mixture - 11H-24 After 12 cycles of Wetting-and-Drying
Volume and Moisture change specimen; 1 @ 12% cement brushed soil-
cement loss specimen; 2 @ 8%; 3 @ 10%; 4 @ 12%, 5 @ 14%.



Standard Mixture - 11H-24 After 12 cycles of Freezing-and-Thawing
Volume and Moisture change specimen; 6 @ 12% cement brushed soil-
cement loss specimens; 7 @ 8%; 8 @ 10%, 9 @ 12%, 10 @ 14%.